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Multi-objective optimal power flow considering the cost, emission, voltage deviation and power losses using multi-objective modified imperialist competitive algorithm

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ABSTRACT

This study presents a new MOMICA (Multi-Objective Modified Imperialist Competitive Algorithm) for the multi-objective OPF (optimal power flow) problem. The OPF problem can be solved for minimum generation cost which satisfies the power balance equations and system constraints. However, cost based OPF problem solutions usually result in unattractive system emission, losses and voltage profiles. In this paper, the fuel cost, emission, voltage deviation and active power losses impacts are considered as the objective functions for the proposed multi-objective OPF problem. The obtained final optimal solution using MOMICA is compared with that obtained using multi-objective algorithm in the literature. The performance of multi-objective algorithms is studied and evaluated on the standard IEEE 30-bus and IEEE 57-bus power systems. The proposed MOMICA method provides better results compared with the other algorithm as demonstrated by simulation results.

1. Introduction

The OPF (optimal power flow) problem is very important in energy management systems. This problem is a static non-linear, non-convex, large-scale and static programming problem which optimizes a certain objective function while satisfying a set of physical and operational constraints imposed by equipments and power system limitations. Nodal power balance equations and restrictions of all control or state variables are examples of equality constraints and inequality constraints. The control variables include the generator real powers, the generator bus voltages, the tap ratios of transformer and the reactive power generations of VAR (volt amperes reactive) sources while state variables involve the generator reactive power outputs, load bus voltages and flow of the network lines. Accordingly, the OPF problem is considered as a basic tool allowing electric utilities to characterize secure and cost effective operating conditions for an electric power system [1].

In recent decades, various population-based optimization techniques have been applied to solve complex constrained optimization problem which also include optimization problem in field of power systems such as OPF problem. Generally, achieving optimal or near optimal solution for a specific problem requires multiple trials as well as accurate adjustment of associated parameters. Some of the proposed population-based methods such as MDE (Modified Differential Evolution) algorithm [2] presents algorithm for solving OPF problem with non-convex and non-smooth generator fuel cost, DE (Differential Evolution) [3] with different objective functions that reflect total fuel cost minimization, voltage stability enhancement, and voltage profile improvement, an ISS (Improved Scatter Search) method to deal with multi-objective EED (Environmental/Economic Dispatch) problems [4], which is formulated as a large-scale highly constrained nonlinear multi-objective optimization problem, based on concepts of Pareto dominance and crowding distance and a new scheme for the combination method [5], a new DQLF (Decoupled Quadratic Load Flow) solution with EGA (Enhanced Genetic Algorithm) [6] to solve the OPF problem for simultaneous minimization of fuel cost, loss and voltage stability index, a proposed DPOPF (Distributed and Parallel OPF) algorithm for smart grid with

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Nomenclature

Abbreviation

CHPED combined heat and power economic dispatch
DPOPF distributed and parallel OPF
DQLF decoupled quadratic load flow
ED economic dispatch
EED environmental/economic dispatch
EPD economic power dispatch
IEEE Institute of Electrical and Electronics Engineers
OPF optimal power flow
VAR volt amperes reactive

Symbols

α_i, b_i, c_i fuel cost coefficients of the *i*th generator
B_{ij} susceptance of between bus *i* and bus *j* (p.u.)
$F_{Ci}(P_{Gi})$ fuel cost of the *i*th generator
G_{ij} conductance between bus *i* and bus *j* (p.u.)
Gi generating unit *i*
MVA mega volt-amperes
NB number of buses
NC number of shunt VAR compensators
NG number of total generator
NPQ number of PQ buses
NTL number of transmission lines
NT number of tap regulating transformers
P_{Di} active load demand of *j*th bus (MW)
P_{Gi} generator active power output of generating unit *i* (MW)
P_{Gi}^{min} minimum active power output of *i*th generating unit (MW)
P_{Gi}^{max} maximum active power output of *i*th generating unit (MW)
Q_{Ci} shunt VAR compensation of *i*th shunt compensator (MVAR)
Q_{Di} reactive load demand of *j*th bus (MVAR)
Q_{Gi} generator reactive power output of unit generating *i*th (MVAR)
Q_{Gi}^{min} minimum reactive power output of *i*th generating unit (MVAR)
Q_{Gi}^{max} maximum reactive power output of *i*th generating unit (MVAR)
Q_{Ci}^{min} minimum VAR injection limit of *i*th shunt compensator (MVAR)
Q_{Ci}^{max} maximum VAR injection limit of *i*th shunt compensator (MVAR)
S_{li} transmission line loading of *i*th branch (MVA)
S_{li}^{max} maximum apparent power flow limit of *i*th branch (MVA)
T_i transformer taps settings of *i*th transformer (p.u.)
T_i^{max} maximum tap settings limit of *i*th transformer (p.u.)
T_i^{min} minimum tap settings limit of *i*th transformer (p.u.)
V_{Gi} generation bus voltages of *i*th generating unit (p.u.)
V_{Gi}^{min} minimum generator voltage of *i*th generating unit (p.u.)
V_{Gi}^{max} maximum generator voltage of *i*th generating unit (p.u.)
V_i voltage of *i*th bus (p.u.)
V_j voltage of *j*th bus (p.u.)
V_{Li} load voltage of *i*th bus (p.u.)
V_{Li}^{min} minimum load voltage of *i*th bus (p.u.)
V_{Li}^{max} maximum load voltage of *i*th bus (p.u.)
x^{lim} limit value of the dependent variable *x*
δ_{ij} phase difference of voltages between bus *i* and bus *j* (Rad)
λ_P, λ_V, λ_Q, λ_S penalty factors
ϕ_h weight factor related to the *h*th objective function
γ_i, β_i, ξ_i, λ_i emission coefficients of *i*th generator (γ_i (ton/h MW^2), β_i (ton/h MW), α_i (ton/h) are related to SOX, and ξ_i (ton/h), λ_i (1/MW) are related to NOX)

Abbreviation of algorithms

ABC artificial bee colony
BB-MOPSO bare-bones multi-objective particle swarm optimization
BBO biogeography-based optimization
DE differential evolution
ECSS enhanced charged system search
EGA enhanced genetic algorithm
FCASO fuzzy adaptive chaotic ant swarm optimization
FFA firefly algorithm
FPSO fuzzy evolutionary and particle swarm optimization
GSA gravitational search algorithm
HS harmony search
ICA imperialist competitive algorithm
IPSO improved particle swarm optimization
ISS improved scatter search
MDE modified differential evolution
MNSGA-II modified non-dominated sorting genetic algorithm
MOHS multi-objective harmony search
MOICA multi-objective imperialist competitive algorithm
MOMICA modified MOICA
MPSO modified particle swarm optimization
MPSO- SFLA hybrid of MPSO and SFLA
MSFLA modified shuffle frog leaping algorithm
NKEA neighborhood knowledge-based evolutionary algorithm
SFLA shuffle frog leaping algorithm
SQP sequential quadratic programming
TLA teaching learning algorithm

Symbols for ICA

BCS best compromise solution
C_n normalized cost of *n*th imperialist
c_n cost of *n*th imperialist
m number of unconquered answers
$N_{country}$ size of initial population of algorithm
N_{col} size of initial population of colonies for imperialist
N.C.n initial total number of colonies
N_{imp} size initial population of empires
N_{var} number of parameters (control variables)
$N.T.C_n$ normalized cost of *n*th empire
T.C.n total cost of the *n*th empire
U uniform distribution

Subscripts

C shunt compensator
D load demand
G generating unit
L load
l line
P active power
Q reactive power
S transmission line loadings
V voltage